Ogden Air Logistics Center

Autonomy - How much is too much?

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Overview

- What is autonomy?
- Brief history of autonomous robots
- Current field use of robots
- Current state-of-the-art for autonomous robots
- Barriers to the use of autonomous robots
- Considering the human factor
- Outlook for the future

What is Autonomy?

- **The dictionary definition**

au·tom·a·ton (ô-tŏm'ə-tən, -tŏn')
_n._, _pl._ -tons or -ta (-tə).

1. **A self-operating machine or mechanism, especially a robot.**
2. **One that behaves or responds in a mechanical way.**

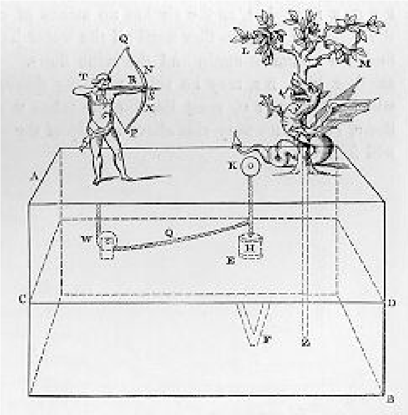
[Latin, self-operating machine, from Greek, from neuter of _automatos_, self-acting.][1]

What is Autonomy?

- A fully autonomous robot has the ability to
  - Gain information about the environment.
  - Work for an extended period without human intervention.
  - Move either all or part of itself throughout its operating environment without human assistance.
  - Avoid situations that are harmful to people, property, or itself.
- An autonomous robot may also learn or gain new capabilities like adjusting strategies for accomplishing its task(s) or adapting to changing surroundings.[2]

Brief History of Autonomous Robots

- **Automata**
  - **Mechanical automata have been popular in many cultures throughout the ages**
  - **Hero of Alexandria designed a number of water- and air-powered automata[3][4]**
  - **Leonardo da Vinci designed and built a number of lifelike automata, including a walking lion with a Fleur deLis in his chest for a state visit by King Louis XII and an automated knight that could sit up, raise his arm, and move his head and jaw[5][6]**



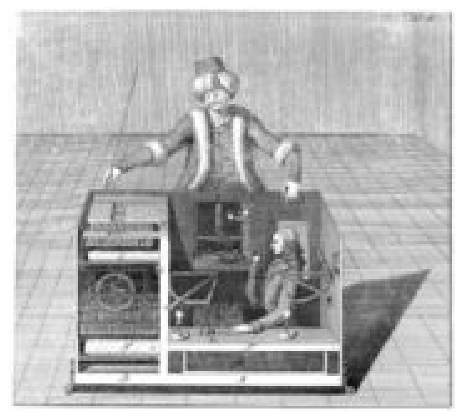
Hero's Hercules shoots a dragon

Leonardo's Knight (reproduction)

Brief History of Autonomous Robots

- Automata
  - The 18th and 19th centuries were a golden age for automata
  - Jacques de Vaucanson created a number of automata; including a flute player, a tambourine player, and his masterpiece – a duck that could flap its wings and eat and digest grain[7]
  - Constructed in 1770 and remaining in use for decades afterward, the Turk was perhaps the most famous automaton ever constructed – it played chess at a master's level and was eventually revealed to be a hoax[8]

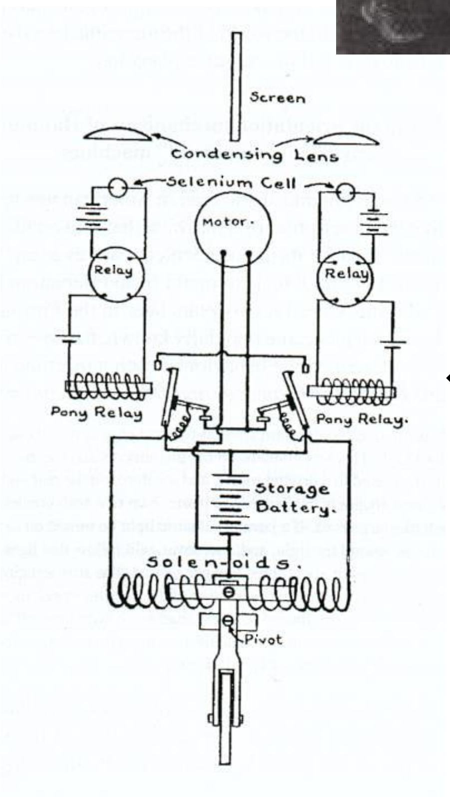
Illustration of Vaucanson's automata



The Turk (and its secret)

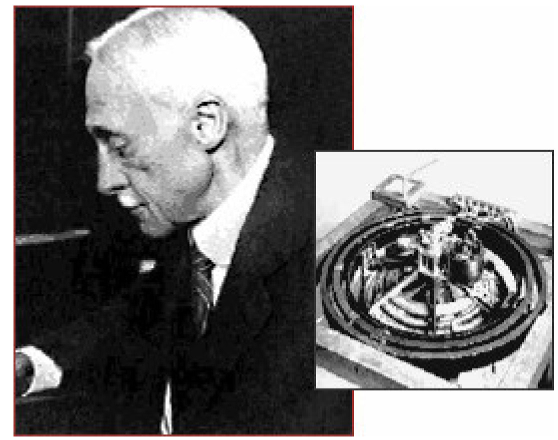
Brief History of Autonomous Robots

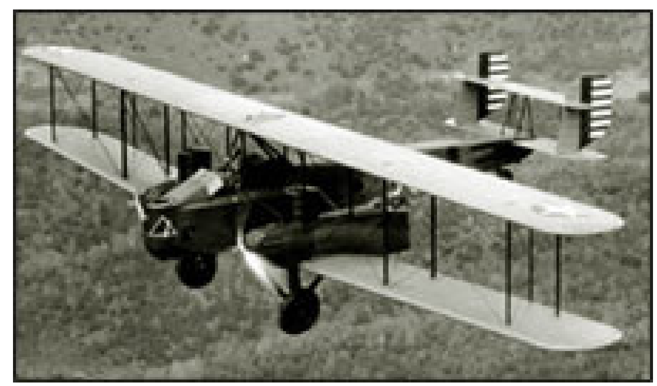
- Electric Dog (1912)
  - The electric dog was developed by John Hammond, Jr. and Benjamin Miessner[9] in 1912
  - This was the first documented implementation of a self-directed, phototropic robot
  - The objective was to use the control circuit for self-directed aerial or naval torpedoes
  - Note how simple the robot controller is, yet it can produce seemingly intelligent behavior
  - This same phenomena was described 70 years later by Valentino Braitenberg in his book about behavioral *Vehicles*[10]



Brief History of Autonomous Robots

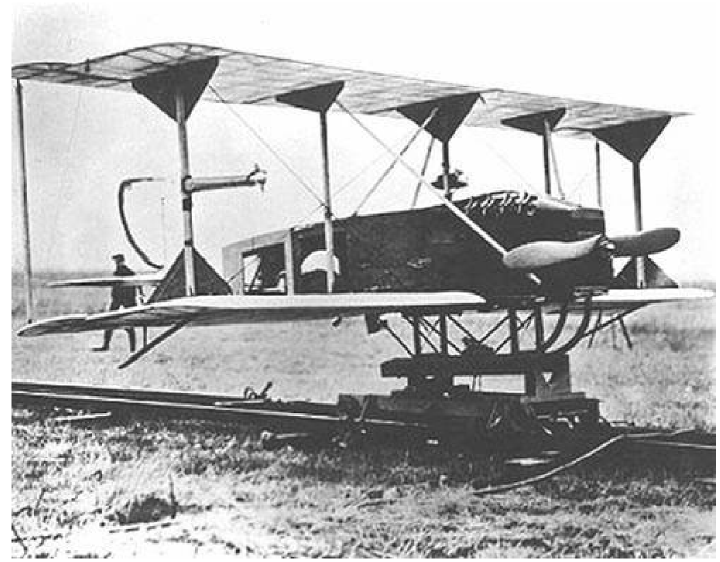
- Sperry Autopilot (1914)
  - Lawrence Sperry, son of Elmer Sperry – the inventor of the gyroscope, modified a Curtis C-2 with gyroscopically-controlled, hydraulically-driven flight surfaces – the first autopilot
  - At a demonstration on June 18, 1914 he astonished the judges by standing on the wings while the autopilot flew the aircraft[11]
  - In 1922, the Sperry Gyro Pilot (“Iron Mike”) was fitted on the Standard Oil tanker W. H. Tilford for the first Atlantic crossing under automatic control[12]





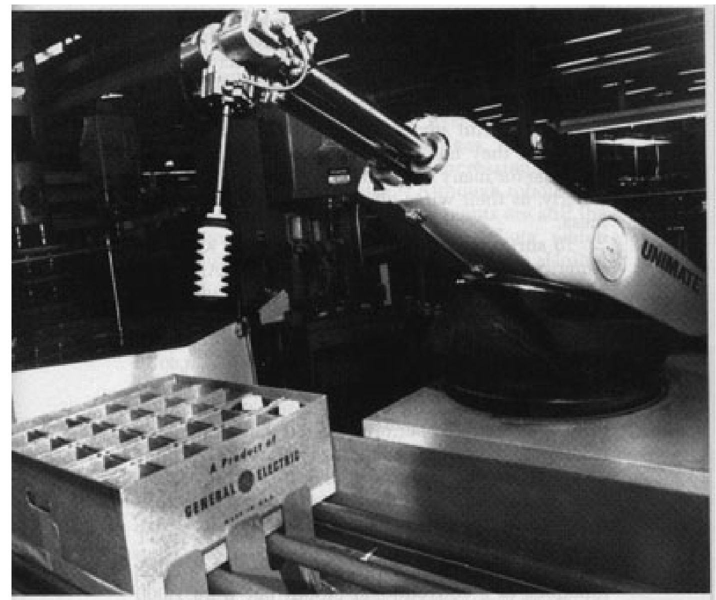
Brief History of Autonomous Robots

- **Sperry "Flying Bomb" (1917)/ Kettering "Bug" (1918)**
  - **America's entry into World War I prompted parallel developments of autonomous flying bombs by the Navy (the Sperry "Flying Bomb") and the Army (the Kettering "Bug")[13][14][15]**
  - **These were the first cruise missiles and they used the recent invention of the gyroscope by Elmer Sperry to control the aircraft in flight**
  - **Of the two, the Bug was the more successful in testing, but neither autonomous aircraft saw combat**



Brief History of Autonomous Robots

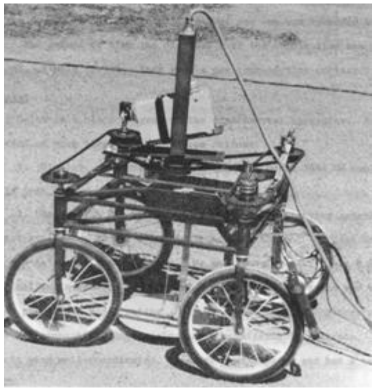
- **Unimate (1961)**
  - **Developed by George Devol and Joseph Engelberger, the Unimate was the first industrial robot[16]**
  - **It was installed on the GM assembly line in 1961, after five years of development**
  - **The 4000-pound robot arm removed parts from die casting machines and performed welding tasks**
  - **The desired movements of the robot were stored on a magnetic drum, developed by Devol[17]**

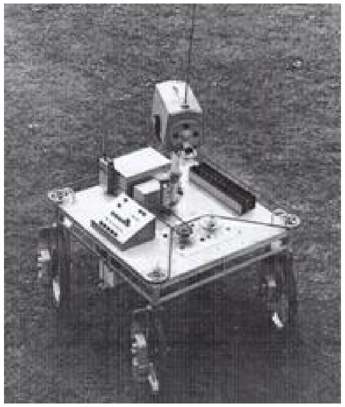


Armed for duty. A Unimate robot—really, just an arm—picks up and puts down parts in a General Electric factory.

Brief History of Autonomous Robots

- Stanford Cart (1961)
  - The Stanford Cart began as a PhD project by James Adams to explore the feasibility of real-time control of a lunar rover using a video feed from Earth (it wasn't)
  - Various PhD students used it over the years for their dissertation research
    - Predictive steering control (Paul Braisted, 1962-1963)
    - Autonomous navigation on a road (Les Earnest, 1966-1971)
    - Indoor navigation using stereo vision (Hans Moravec, 1971-1980)
  - The Cart is generally considered to be the predecessor to today's programmable mobile robots[18]





Brief History of Autonomous Robots

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- Automatically Operated Car (1977)
  - The first demonstration of a driverless car occurred in 1977 in Tsukuba, Japan[19][20]
  - The car was a delivery van that was modified by the Mechanical Engineering Laboratory (now part of the National Institute of Advanced Industrial Science and Technology)
  - The car used machine vision and control systems for automated navigation and obstacle avoidance
  - It was capable of navigating up to 50 meters on empty roads, at speeds up to 30 km/h

Automatically Operated Car

Current Field Use of Robots

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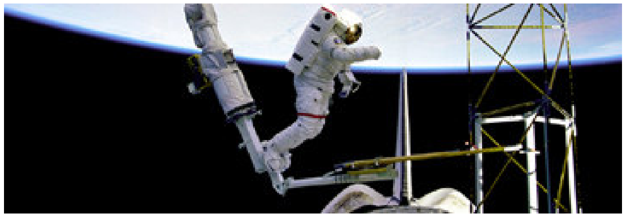
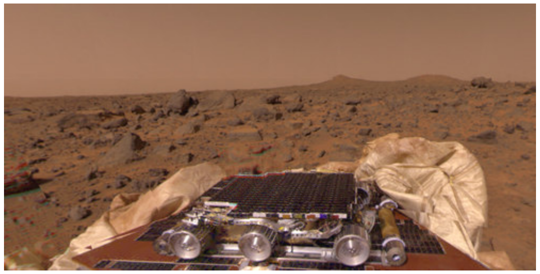
- **Space**
  - **While not usually thought of as robots, most spacecraft (satellites, probes, etc.) are robots**
  - **The Space Shuttle and the International Space Station both have robotic manipulators for moving large objects, grasping objects, and use as mobile work platforms for astronauts**
  - **The best known space robots are the Mars exploration robots – Sojourner, Spirit, and Opportunity[21]**





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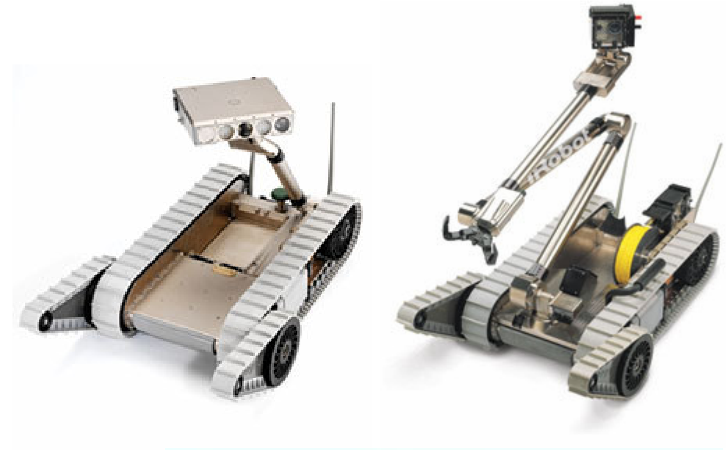
Current Field Use of Robots

- **Air**
  - **Cruise missiles are the only aerial robots typically used fully autonomously[22]**
  - **Converted aircraft or purpose built drones are used for pilot training and weapons testing[23]**
  - **Unmanned Aerial Vehicles are widely used for reconnaissance and combat missions and can be operated mostly autonomously, but they are always human supervised[24]**

Current Field Use of Robots

- **Land**
  - **Robots have been primarily used as tele-operated remote eyes and hands in hazardous situations**
  - **In SWA, robots have been extensively deployed for scouting and bomb disposal tasks[25]**
  - **The DOE has been developing robots for decades for use in radiation hazard sites[26]**
  - **Commercially, some autonomous robots are being used in homes[25]**



Current Field Use of Robots

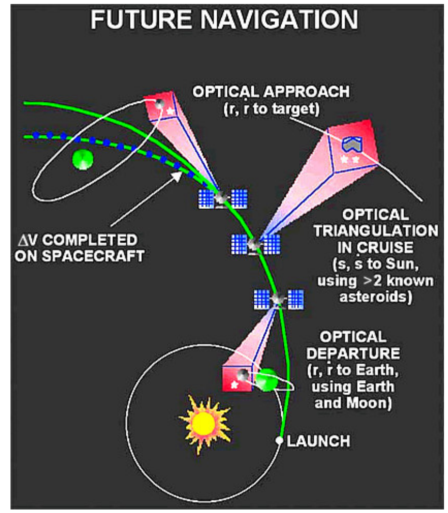
- **Sea**
  - **Most robots currently used in maritime applications are remote controlled submersibles for demining operations, submarine rescue, or for deep water exploration[27]**
  - **The National Deep Submergence Facility of Woods Hole Oceanographic Institution is currently operating two fully autonomous deep sea submersibles (ABE and Sentry) to survey the ocean floor for follow-on remote vehicle exploration[28]**

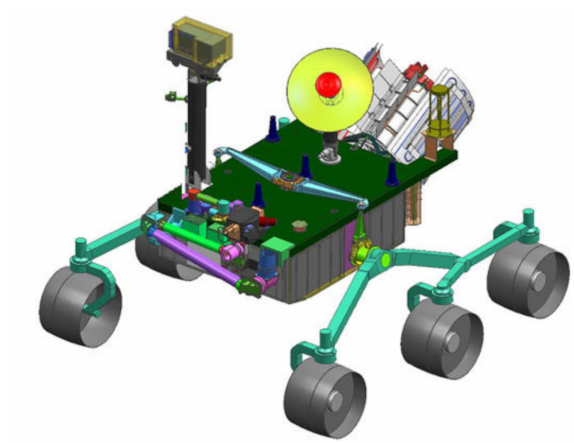
Current Field Use of Robots

- Search and Rescue
  - With the exception of remotely-operated submersibles for underwater rescue, robots have not been widely used in search and rescue operations
  - A number of robots have been deployed to disaster areas, including the World Trade Center and Hurricane Charley – mostly by the Center for Robot-Assisted Search and Rescue
  - Robots haven't played a key role in any rescue scenario, often being used for exploring less critical areas or for getting a camera into a location that is too difficult for human or animal rescuers[29]

Current State-of-the-Art for Autonomous Robots

- Space
  - NASA's Deep Space 1 was the first space probe to demonstrate fully autonomous navigation[30]
  - The European Robot Arm, scheduled for delivery to the ISS in 2009, is capable of repositioning itself and of carrying out a number of tasks autonomously[31]
  - The Mars Science Laboratory, planned for launch in 2009, will be much larger than the current rovers and will traverse much more terrain – which will require a higher degree of autonomy[32]





Current State-of-the-Art for Autonomous Robots

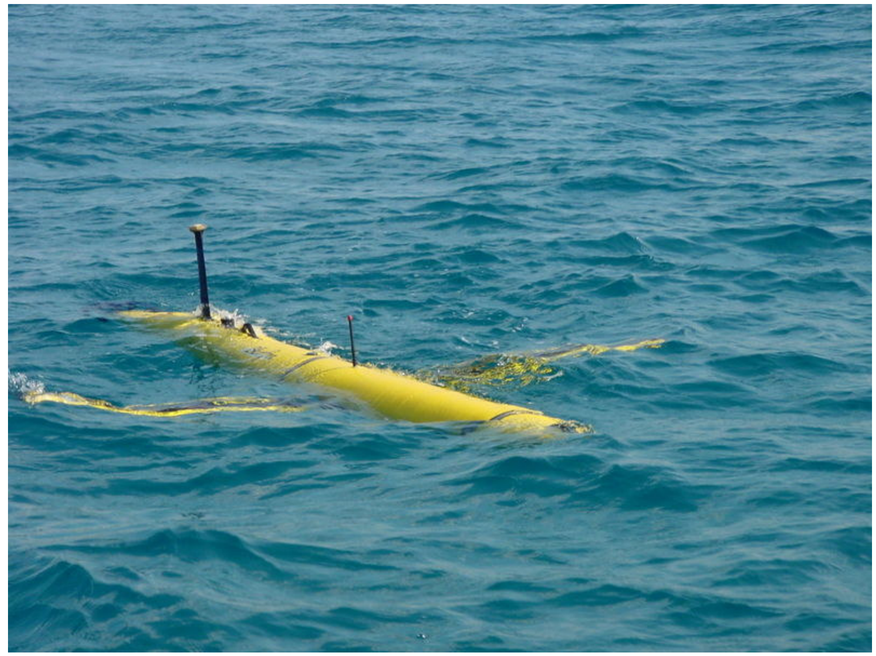
- **Air**
  - **Fully autonomous aircraft are flying today**
  - **With the arming of the Predator and the new Reaper UAVs, autonomous combat would be theoretically possible, but not allowed by current doctrine**
  - **The next step in the evolution of fully autonomous aircraft would be unmanned fighter/bombers, such as the Boeing X-45 Unmanned Combat Air Vehicle shown here that is currently in development[33]**

Current State-of-the-Art for Autonomous Robots

- **Land**
  - **Groups from CMU and the University Bundeswehr Munich independently demonstrated autonomous drives on highways with traffic in 1995[20]**
  - **The US DOT conducted tests of the Automated Highway System on a closed freeway in San Diego, California in 1997[34]**
  - **In 2005, Stanford University won the DARPA Grand Challenge by autonomously traversing 132 miles of desert terrain in just under 7 hours[35]**
  - **The 2007 DARPA Urban Challenge will have contestants operate in an urban environment, while obeying traffic laws and avoiding vehicular and pedestrian traffic**

Current State-of-the-Art for Autonomous Robots

- **Sea**
  - **Advances in autonomous sea exploration are largely being driven by oil and gas exploration companies who want to map the ocean floor to identify areas for further exploration, scientific researchers who are interested in deep ocean exploration, and military counter-mine research**
  - **At present, there are only a few mass produced AUVs, such as the Bluefin-12 pictured here in trials with the US Navy[36]**



Current State-of-the-Art for Autonomous Robots

- Search and Rescue
  - The International RoboCup Federation and the US National Institute of Standards and Technology have been the primary sponsors of research into autonomous search and rescue robots
  - The two venues for this research are the annual RoboCupRescue Robot competition and the annual RoboCupRescue Robot League Camp[37]

Barriers to the Use of Autonomous Robots

- Reliability
  - While improving, most robots are still limited by short-lived power sources, mechanical and electronic failures, and cognitive breakdowns
- Adaptability
  - Nearly all successful robots have been purpose built – they aren't good generalists
- Availability
  - Demand for robots typically far outpaces the supply and development of a new robot can take a long time
- Cost
  - Most commercially available, non-hobby robots are very expensive
- Acceptance
  - Most people are not ready to fully trust a robot (not without good reason, at present)

Considering the Human Factor

- Robots are capable of more autonomy than they are usually allowed to use
- In most environments where robots need to operate in close proximity to humans, the robots are very restricted in their autonomy or are only operated under human control
- Especially in hazardous environments, such as combat zones or disaster areas, there is no tolerance for unpredictable behavior from a robot (there's already enough uncertainty inherent in the environment)
- Then there is a question of who's responsible if an autonomous robot injures or kills a person[38]

Considering the Human Factor

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- Some of these concerns are being dealt with now as robots become more prevalent in combat and SAR scenarios
- As humans work with robotic partners, they tend to anthropomorphize them
  - An example is the story of the EOD technician in Iraq who brought a small box into the robot repair shop – it contained all that remained of "Scooby-Doo", an EOD robot[38]
  - The technician was offered a new robot, but he didn't want a new robot – he wanted Scooby back!
- As we increasingly rely on robots, our trust in the robots will grow and we may even start to feel some affection for our mechanical companions

Considering the Human Factor

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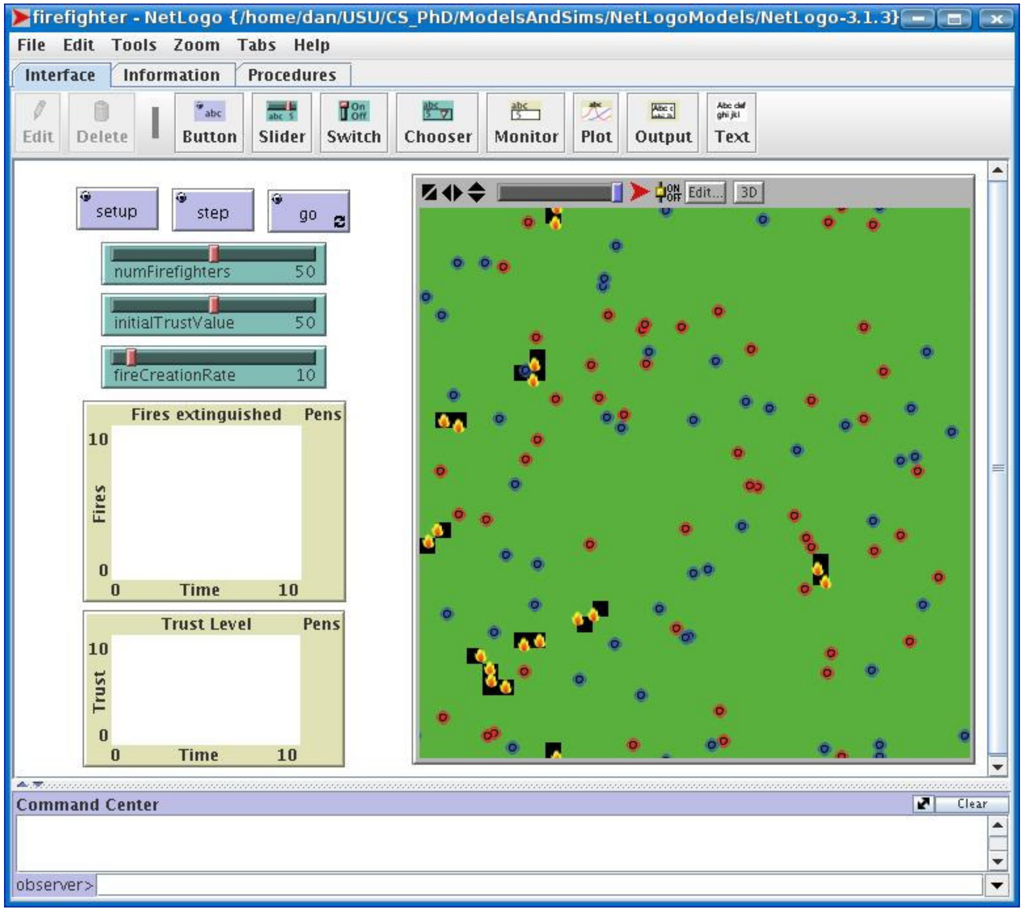
- What would it take to make humans trust robots?
  - To attempt to answer this question, I developed an agent-based firefighting simulation
  - The simulation allows the adjustment of parameters for the number of fires that need to be extinguished, the numbers of human (and robotic) firefighters, and the initial trust value that humans place in the robots



Considering the Human Factor

- What would it take to make humans trust robots?
  - There is still more work to be done on the simulation, but the critical factors appear to be the obvious ones
    - Reliability of the robots
    - The extent of the workload and fatigue
    - The availability of other human firefighters vs the availability of robots
  - Some of the factors that would also seem to be important, but harder to model, are individual human characteristics – such as willingness to accept new technologies and adaptability to change

Outlook for the Future

- Autonomous robots are rapidly approaching the point where they can operate reliably – even in challenging environments
- Sophisticated reasoning about the environment is still a long way off
  - For example, much more development of robot cognitive abilities will be needed before a robot can decide whether a person approaching it has hostile intent or not
- The major obstacle for autonomous robots is not a technical one (although robotic intelligence still needs much work), but an issue of human trust
  - Are we humans ready to accept the potential consequences of arming an autonomous robot?

Outlook for the Future

Robotic Battletank from the movie *Terminator*[39]

Questions?

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